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NP-12660

Report Number

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United States Atomic Energy Commission

Division of Technical Information

OTI-131(May 1962)

USAEC Division of Technical Information Extension, Oak Ridge, Tennessee

NP-12660

MASTER

GAMMA-GAMMA ANGULAR CORRELATION
IN THE DECAY OF COBALT-60

by
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Submitted in partial fulfillment of
the requirements for the degree of
MASTER OF SCIENCE
IN
PHYSICS

UNITED STATES NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA
1961

Rept. no. NP-

GAMMA-GAMMA ANGULAR CORRELATION
IN THE DECAY OF COBALT 60

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BURTON J. CONWAY

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BURTON J. CONWAY

This work is accepted as fulfilling
the thesis requirements for the degree of
MASTER OF SCIENCE
IN
PHYSICS
from the
United States Naval Postgraduate School

Harry E. Handler
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Chairman
Department of Physics

Approved:

C. E. Linell
Academic Dean

ABSTRACT

This is a continuation of the work of assembling and testing the equipment necessary to conduct gamma-gamma angular correlation experiments, started by Fort A. Verser, Jr. at the US Naval Postgraduate School ~~(1)~~.

~~No substantial changes were made in the equipment, but rather~~ a rerun of the Cobalt-60 experiment was made to confirm the results obtained in the previous work. A comparison of the previous work confirms that there is a definite distortion in the shape of the observed correlation function.

The statistical analysis of the data and the solid angle corrections required for evaluation of the results have been programmed for calculation by use of the 1604 Digital Computer. This paper outlines these programs in detail.

The author wishes to express his appreciation for the assistance given him by Professor Harry E. Handler and for his guidance throughout this investigation. Appreciation is expressed to Professor Edmund A. Milne for his advice and comments. Captain T. R. Abernathy, USMC, was very helpful in providing valuable assistance and discussions on various aspects of the computer programing. The cooperation and assistance of Mr. Mervyn C. Brillhart in maintaining and testing the electronic equipment was indispensable.

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CHAPTER I
INTRODUCTION

The decay of Cobalt-60 to an excited state of Nickel-60 and the angular correlation of the resulting gamma-gamma cascade have been studied extensively experimentally (2,6,8,9, and others) and the results of the correlation measurements agree very well with the theoretical correlation for the decay scheme shown in Figure 1. Consequently, the decay of Cobalt-60 is now used as one standard for the testing of correlation equipment.

Angular correlation equipment was assembled at the US Naval Postgraduate School by Verser in 1960 for the investigation of the properties of low-lying excited nuclear states. His testing of the operating characteristics of the equipment by the angular correlation of the cascading gamma rays resulting from the decay of Cobalt-60 yielded an observed correlation curve whose shape was not in agreement with the theoretical curve. This work was initiated in order to attempt to verify Verser's results.

In order to facilitate the statistical analysis of the data, a program has been worked out for the use of the 1604 Digital Computer. The program follows the procedures outlined by M.E. Rose (2) and is contained completely in Appendix I.

An additional program has been written to compute the solid angle corrections, which must be applied to the theoretical curve, by the method of M.E. Rose (2). This progam is outlined in Appendix II.

The results of this work agreed within statistical expectation with those obtained by Verser, indicating that the unexpected shape of the curve is apparently real and not an instrumental effect. These results are given in Chapter VI.

PARTIAL DECAY SCHEME OF COBALT-60

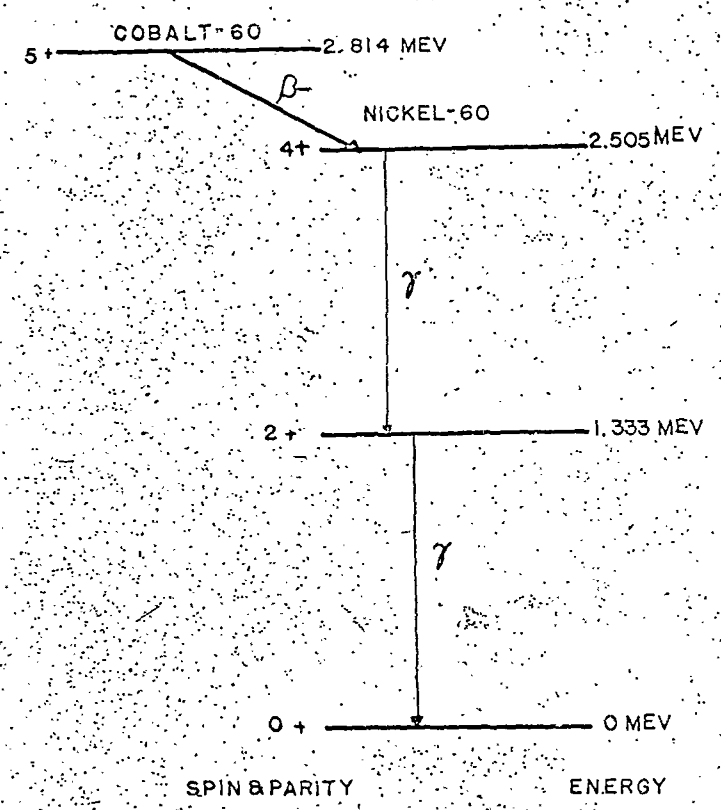


FIGURE I

CHAPTER II
THEORETICAL CONSIDERATIONS

The determination of the angular momentum quantum numbers, or spins, of low-lying short-lived excited nuclear states by the nuclear spectroscopic tool, known as angular correlation of successively emitted radiations, is quite common practice today. Only within recent years, because of the vast advancement of electronics, has practical utilization of this tool become possible.

Since nuclei, under ordinary conditions, are randomly oriented in space, it is not possible to observe a radiation pattern. This is due to the fact that the probability of emission of a radiation by an excited nucleus, depends on the angle between the nuclear spin axis and the direction of the emission. Therefore, in order to observe a radiation pattern, it is first necessary to orient the nuclei.

One method of orienting certain nuclei consists of placing the sample in an electric field gradient or a strong magnetic field at a very low temperature. Another method, the one used in the present consideration, consists of selecting nuclei whose nuclear states have spins lying in preferred directions. This happens to be the case for the intermediate state if a nucleus decays by successive emission of two radiations.

In an angular correlation experiment the first radiation is observed in a fixed direction. This establishes an axis to which the direction of emission of the second radiation, originating from the state formed by the first, can be referred. The second radiation has preferred angles of emission with respect to the direction of the first.

In order that the correlation exhibit maximum anisotropy, the angular momentum vector of the intermediate state must not change

direction significantly before the second radiation occurs. The mean life of the intermediate state must be less than about 10^{-8} seconds, the typical precession period of the nuclear spin about local perturbing fields. The angular correlation function is determined by the nature of the radiations and by the spins of the states involved, and thus its measurement may lead to an unambiguous choice of spins for the states.

The theoretical expressions for the correlation functions have been worked out for a large number of cases of interest (7). For the particular case of a gamma-gamma cascade, the correlation function $W(\theta)$ is

$$W(\theta) = \sum_{n=0}^{n_{max}} A_n P_n(\cos\theta) = \sum_{n=0}^{n_{max}} B_n \cos^n\theta \qquad (1)$$

where P_n is the Legendre Polynomial of even order n, n_{max} is the smallest even integer of the set of three numbers consisting of twice the multipole order of each of the two gamma rays, and θ is the angle between the directions of emission of the two gamma rays.

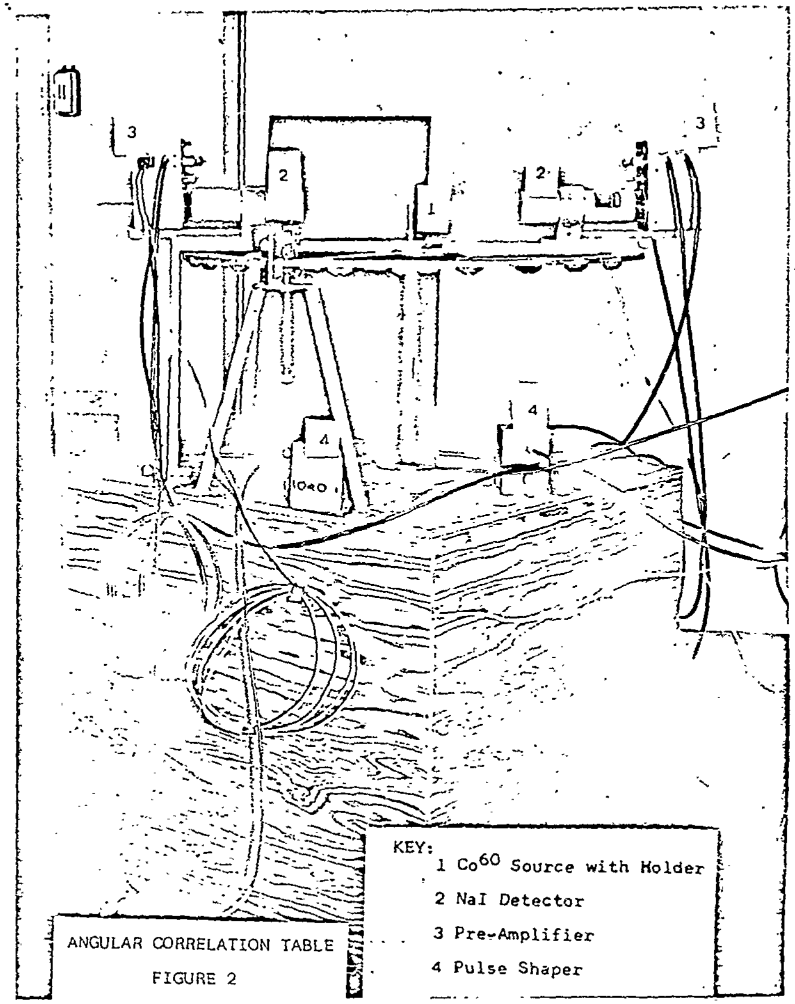
The theoretical correlation function for the cascade in Nickel-60, assuming point detectors and a point source, is

$$W(\theta) = 1 + 0.1020\, P_2(\cos\theta) + 0.0091\, P_4(\cos\theta) \qquad (2)$$

with an anisotropy

$$R = \frac{W(180^\circ) - W(90^\circ)}{W(90^\circ)} = 0.1667 \qquad (3)$$

Many workers, after correcting these theoretical results for the effect of non-point detectors have found good agreement between them and their experimental correlation results.



ANGULAR CORRELATION TABLE

FIGURE 2

CHAPTER III

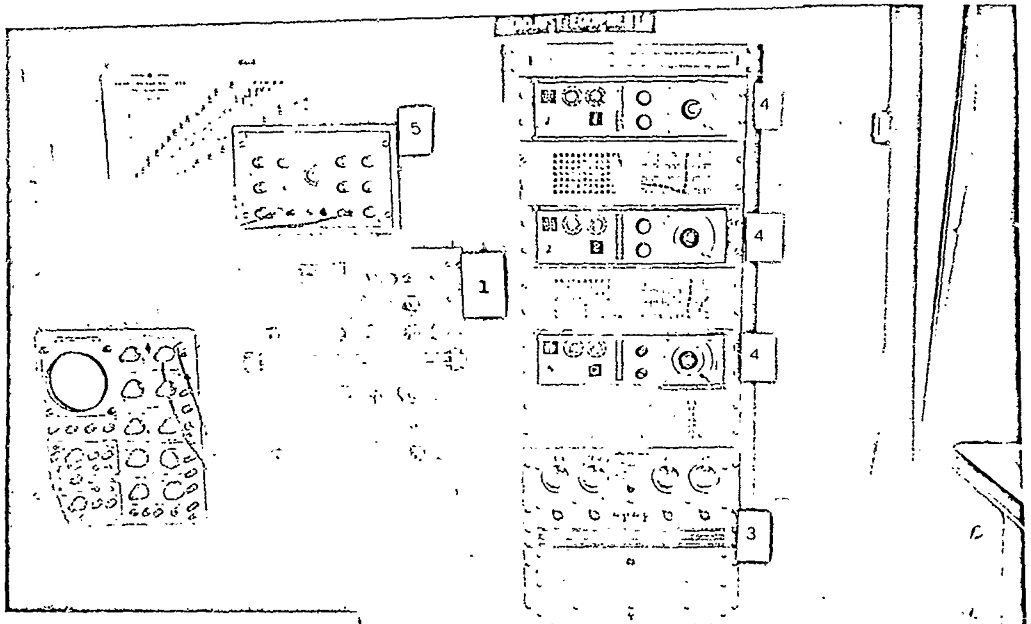
DESCRIPTION OF EQUIPMENT

The equipment needed for the gamma-gamma correlation measurements must furnish means for detecting the radiation, pulse-height amplification with selection or discrimination, coincidence analysis, and adequate recording of the counts in the various counting channels. A mechanical system must also be provided for mounting the detectors and changing their relative positions and for holding and positioning the radioactive source.

The apparatus used for this work was that assembled by Verser and described in detail in his report. Therefore, only a brief description of the equipment and of the minor alterations performed on it will be presented.

Figure 2 is a photograph of the mechanical setup. The original base of the correlation table has been replaced, the new base is of solid brass with a bearing mounted shaft to enable accurate manual detector positioning.

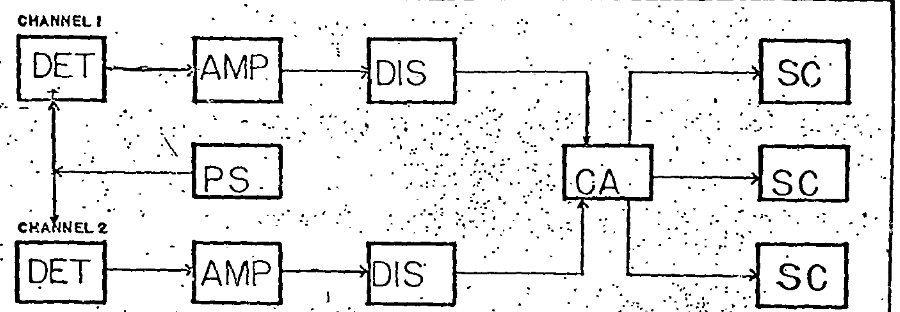
The electronic equipment (Figure 3) has the functions of detection of the radiation, pulse-height amplification and discrimination, coincidence analysis, and recording the number of counts. The only change in the electronic equipment was in the pulse-shaping networks used in the initial calibration of the apparatus. The pulse shapers were rebuilt to give a better simulation between the test pulses and the actual pulses encountered under operating conditions.



KEY:
1. Linear Amplifiers
2. High Voltage Power Supply
3. Coincidence Analyzer
4. Glo-Tube Scaler
Double Pulse Generator

ELECTRONIC SYSTEM

FIGURE 3



KEY: DET - DETECTOR
AMP - LINEAR AMPLIFIER
DIS - DIFFERENTIAL DISCRIMINATOR
SC - GLO-TUBE SCALER
PS - HIGH VOLTAGE POWER SUPPLY
CA - COINCIDENCE ANALYZER

SCHEMATIC DIAGRAM OF THE ELECTRONIC SYSTEM

FIGURE 4

CHAPTER IV

EXPERIMENTAL ANALYSIS

The angular correlation function $W(\theta)$ (Equation 1) must be expressed in terms of experimentally-observable quantities. The equipment records the total number of coincidences as a function of the angle between the detectors, and the total number of radiations captured in each channel. C_t, the total number of coincidences in a counting period, is given by

$$C_t = C_g + C_a + C_b \tag{4}$$

where

C_g = the number of genuine coincidences due to the two cascading radiations,

C_a = the number of accidental coincidences due to the finite resolving time of the electronic equipment, and

C_b = the number of background coincidences.

The half-life of the source is long compared to the time required to collect the necessary data; therefore, equation (4) can be re-arranged and rewritten in terms of counting rates:

$$\dot{C}_g = \dot{C}_t - \dot{C}_a - \dot{C}_b \tag{5}$$

$\dot{C}_g$ can also be expressed in terms of other parameters:

$$\dot{C}_g = (\varepsilon_{11}\alpha_{11}\rho_{11}\,\alpha_{22}\rho_{22} + \varepsilon_{12}\alpha_{12}\rho_{12}\varepsilon_{21}\alpha_{21}\rho_{21})\Omega_1\Omega_2\phi_{12}\dot{N}_0\overline{W}(\theta_i) \tag{6}$$

where

$\dot{N}_o$ = the absolute source strength

ϕ_{jk} = the fraction of nuclei decaying by the emission of gamma ray "j" and gamma ray "k" in a cascade

Ω_i = the fractional solid angle subtended by the crystal in Channel "i"

ρ_{ij} = the fraction of gamma rays "j" which leave the source in the right direction to enter crystal "i" that are not absorbed before reaching the crystal

ε_{ij} = the total efficiency of the crystal in Channel "i" for gamma ray "j"

α_{ij} = the fraction of the number of gamma rays "j" captured by the crystal in Channel "i" whose pulse heights are accepted by the energy discrimination of Channel "i"

$\overline{W}(\theta_m)$ = the angular correlation function at an angle θ_m averaged over the solid angles used.

$\dot{N}_i$, the counting rate in Channel "i", can also be expressed as a function of certain of these same parameters.

$$\dot{N}_i = \Omega_i\,\phi_i\dot{N}_o\sum_j \varepsilon_{ij}\alpha_{ij}\,\rho_{ij} + \dot{N}_{ib} \tag{7}$$

where

ϕ_i = the number of gamma rays "i" per disintegration

$\dot{N}_{ib}$ = the background counting rate in channel "i"

From Equations (5) and (6) we get for the correlation function,

$$\overline{W}(\theta_m) = \left(\frac{\dot{C}_g}{f\dot{N}_o}\right)_m = \left(\frac{\dot{C}_t-\dot{C}_a-\dot{C}_b}{f\dot{N}_o}\right)_m \tag{8}$$

where f is the appropriate function of the ε's, α's, ρ's, and ϕ's.

By combining Equations (7) and (8), we get for the correlation function

$$\overline{W}(\theta_m) = \left\{\frac{(\dot{C}_t-\dot{C}_a-\dot{C}_b)\ \dot{N}_o g}{(\dot{N}_1-\dot{N}_{1b})\ (\dot{N}_2-\dot{N}_{2b})}\right\}_m \tag{9}$$

where g is a function of the ε's, α's, ρ's, Ω's, ϕ's.

In this form $W(\theta_m)$ is relatively insensitive to equipment stability. Therefore, it is only necessary to calculate the modified correlation function given by

$$\overline{W}'(\theta_m) = \frac{\overline{W}(\theta_m)}{g\dot{N}_o} = \left\{\frac{(\dot{C}_t-\dot{C}_a-\dot{C}_b)}{(\dot{N}_1-\dot{N}_{1b})\ (\dot{N}_2-\dot{N}_{2b})}\right\}_m \tag{10}$$

The correlation runs were done with the movable detector at seven angles: 90°, 105°, 120°, 135°, 150°, 165°, and 180°. A minimum of six two-hour counting periods were completed at each angle, and the angular order in which they were taken was varied to minimize any systematic fluctuations. Each run yielded single channel counting rates of approximately 1200 counts per second and a total coincidence rate of approximately 1.1 counts per second.

Before the experimental results can be compared to theory, the data must be checked and corrected, if necessary, for the various deviations from the ideal arrangement, i.e., centered point source, no spurious coincidences due to the coincidence resolving time, no scattering, no background, and perfect stability of the electronic equipment. In addition, the theoretical correlation function must be corrected for non-zero solid angle detectors. The methods for accounting for these effects are discussed in the following paragraphs.

A. SOURCE SIZE AND POSITIONING

As a test of the positioning of the source in the center of the correlation table, the integral counting rate of a portion of the Cobalt-60 spectrum was measured in each channel as a function of the angle between the counters. This was done by Verser and checked again after the base of the correlation table had been changed. Within statistical expectations, the counting rates were constant. The source has a volume of about 0.001 cubic inches and can be regarded as a point source at the distance at which the detectors were placed from it.

B. SCATTERING

Compton scattering occurring outside the detectors can give rise to unwanted coincidences. These in general will tend to smear out the measured correlation function. This problem is minimized by use of scintillation crystals as detectors and accepting only the full-energy peaks of the desired gamma rays. The method for determining the pulse height selection limits has been discussed in detail by Verser.

C. BACKGROUND CORRECTION

With the discriminators at the same settings as were used during the correlation runs, background runs were made before and after the correlation runs. The background coincidence counting rate was negligibly small, and the background rate of each channel was such as to yield total background counts of the order of 0.4 percent of the total counts in each channel during the correlation runs. These background rates were used as corrections to the gross counting rates obtained during correlation runs.

D. DETERMINATION OF GENUINE COINCIDENCE RATE

Since the background coincidence counting rate proved experimentally

to be negligible, Equation (5) becomes

$$\dot{C}_g = \dot{C}_t - \dot{C}_a$$

For the total counting time, T, the total number of coincidences is $\dot{C}_t T$ and the standard deviation in the total coincidence rate is

$$\sigma_t = \sqrt{\frac{\dot{C}_t}{T}} \tag{11}$$

Therefore, the standard deviation of the genuine coincidence rate is

$$\sigma_g^{\,2} = \sigma_t^{\,2} + \sigma_a^{\,2} = \frac{\dot{C}_t}{T} + \frac{\dot{C}_a}{T} \tag{12}$$

The accidental coincidence rate is given by

$$\dot{C}_a = 2\Upsilon_r \dot{N}_1 \dot{N}_2 \sim 2\Upsilon_r \dot{N}_o^2 \tag{13}$$

where

Υ_r = Coincidence resolving time of the coincidence analyzer.

In order to minimize the accidental coincidence rate, the source strength must be kept as small as possible. However, if the source strength is decreased, the counting time must be increased to obtain a specified precision in the counting rate. Thus, a compromise must be reached between precision and counting time.

The smallest resolving time obtainable with the present equipment is experimentally determined to be

Υ_r = (0.1820 ± 0.0016) microseconds;

this resulted in an accidental coincidence rate that was about 30% of the

total coincidence rate. The approximate source strength of the water solution of $CoCl_2$ used in this experiment was 0.05 millicuries of Cobalt-60.

E. REFERENCE COUNTING RATE

With the discriminator in each channel adjusted to accept only the full-energy peaks of the desired gamma rays, the integral counting rate of the Cobalt-60 spectrum in each channel was determined. This gave a reference counting rate for each channel. During the course of the correlation runs, either the discriminator settings or the gains of the linear amplifiers were adjusted before each run so that, the integral counting rate agreed within ± 5 cps with these reference rates (Table 1).

TABLE 1

REFERENCE COUNTING RATES
$\dot{N}_1$ = (1085.26 ± 0.57) cps
$\dot{N}_2$ = (1117.32 ± 0.59) cps

As a measure of the gain fluctuations during each counting run, the integral counting rate of each channel was measured after the run using the same discriminator setting that was employed during the run. The difference between this counting rate and the reference counting for that channel was determined. If the variation exceeded ± 20 cps in either channel, the run was discarded.

This procedure resulted in about 30% of the runs being discarded because they fell outside of the maximum acceptable fluctuation. This indicates that the electronic system is not as stable as it should be. A check of the line voltage revealed substantial fluctuations during any 24-hour period. The temperature of the room was not controlled in any manner and varied considerably. These could have been the major causes of the large counting rate fluctuations since the discriminators are highly sensitive to both temperature and voltage variations.

F. SOLID ANGLE CORRECTIONS

The solid angle correction which must be applied to the theoretical correlation function to account for the non-zero solid angle of the detectors and enable a comparison to be made with the measured function is described by Rose (2). The correction for two cylindrical crystals whose axes intersect at the source involves the numerical evaluation of integrals of the form

$$I_{n,i} = \int_0^{\gamma_i} P_n (\cos \phi) \left\{ 1 - e^{-\Upsilon_i X_i(\phi)} \right\} \sin \phi d\phi \qquad (14)$$

where

Υ_i = the full-energy absorption coefficient of the detector in Channel "i" for the gamma ray;

γ_i = the half-angle subtended by the front face of the crystal in Channel "i";

$$X_i(\phi) = t_i \sec\phi \quad \text{for } 0 \leq \phi \leq \tan^{-1} \frac{-r_i}{h_i + t_i} ;$$

$$X_i(\phi) = r_i \csc\phi - h_i \sec\phi \quad \text{for } \tan^{-1} \frac{r_i}{h_i + t_i} \leq \phi \leq \gamma_i ;$$

where

h_i = the distance from the source to the crystal in Channel "i";

t_i = the thickness of the crystal in Channel "i",

r_i = the radius of the crystal in Channel "i".

The attenuation factors, Q_n, are functions of these integrals:

$$Q_n = \left[\frac{I_{n,1}}{I_{o,1}}\right] \left[\frac{I_{n,2}}{I_{o,2}}\right] \qquad (15)$$

The corrected correlation function becomes

$$\bar{W}(\theta) = \sum_{n=0}^{N_{max}} Q_n A_n P_n (\cos\theta)$$

CHAPTER V
EXPERIMENTAL RESULTS

The modified correlation function for the k^{th} run at angle θ_m given by Equation (10) is

$$\bar{W}'_k (\theta_m) = \left\{ \frac{\dot{C}_t - \dot{C}_a - \dot{C}_b}{(\dot{N}_1 - \dot{N}_{1b})\ (\dot{N}_2 - \dot{N}_{2b})} \right\}_k$$

This means that the seven counting rates $\dot{C}_t$, $\dot{C}_a$, $\dot{C}_b$, $\dot{N}_1$, $\dot{N}_{1b}$, $\dot{N}_2$, and $\dot{N}_{2b}$ must be determined for each run at each angle and the standard deviation of each rate calculated.

The background counting rates $\dot{N}_{1b}$ and $\dot{N}_{2b}$ for each run were experimentally determined. The single-channel counting rates corrected for scaling losses yielded $\dot{N}_1$ and $\dot{N}_2$. The accidental counting rates were calculated for each run from Equation (13). The total coincidence counting rate, $\dot{C}_t$, was experimentally determined. The background coincidence rate, $\dot{C}_b$, was negligible throughout the experiment.

The experimental value of the modified correlation function $\bar{W}'_k (\theta_m)$ and its standard deviation were calculated for each run at each angle. From these the weighted mean $\bar{W}' (\theta_m)$ and its standard deviation were computed for each angle.

The weighted mean of the measurements taken at each angle was determined by using the inverse square of the standard deviation of each measurement as a weighting factor:

$$\bar{W}'(\theta_m) = \frac{\sum_{1}^{N_m} \frac{\bar{W}'_k(\theta_m)}{\sigma_k^2}}{\sum_{1}^{N_m} \frac{1}{\sigma_k^2}} \qquad (18)$$

where N_m = number of runs at the angle θ_m.

The standard deviation of the weighted mean $(\bar{W}')$ was calculated from the individual standard deviations:

$$\frac{1}{\sigma^2(\bar{W}')} = \sum_{1}^{N_m} \frac{1}{\sigma_k^2} \tag{19}$$

A comparison between the standard deviations of the means calculated from Equation (19) and those calculated from

$$\sigma^2(\bar{W}') = \sum_{1}^{N_m} \frac{\left[\bar{W}'(\theta_m) - \bar{W}(\theta)\right]^2}{N_m(N_m - 1)} \tag{20}$$

revealed no significant differences. Therefore the standard deviation obtained from Equation (19) were used in subsequent calculations and the method discussed in paragraph E Chapter IV for treating gain instabilities is realistic.

The values of the weighted means and their standard deviations are tabulated in Table 2.

TABLE 2

The Weighted Means $\bar{W}'(\theta_m)$

θ_m (degrees)	Weighted Mean	Standard Deviation
90	5046	45
105	4925	33
120	5109	21
135	5211	36
150	5556	35
165	5667	24
180	5907	43

A curve of the form $\bar{W}'(\theta) = \sum A'_n \; P_n(\cos\theta)$ was fitted to the experimental $\bar{W}'(\theta_m)$ by the method of least squares as outlined by Rose (2). This analysis was programmed to be carried out by the 1604 computer. (See Appendix II for details).

The values of A'_n are given by the matrix equation

$$\|A'\| = \|A^T \omega A\|^{-1} \cdot \|A^T\| \cdot \|\omega\| \cdot \|\mu\| \tag{21}$$

where

$\|A\|$ = the 7 x 3 matrix consisting of the Legendre Polynomials, P_o, P_2, and P_4, evaluated at the seven angles (Figure 5A).

$\|A^T\|$ = the transposed A matrix

$\|\omega\|$ = a diagonal matrix with elements consisting of the inverse squares of the standard deviations of the experimental $\bar{W}'(\theta_m)$ (Figure 5B)

$\|\mu\|$ = a one column matrix whose elements are the experimental values of $\bar{W}'(\theta_m)$ (Figure 5C)

$\|A'\|$ = the one column matrix whose elements are respectively the least-square coefficients A'_o, A'_2 and A'_4 (Figure 5D)

$\|A^T \omega A\|^{-1}$ = the inverse of the matrix obtained by multiplying the three designated matrices together. The diagonal terms of this matrix are the squares of the standard deviations of the least-square coefficients, A'_n.

The experimental values for the coefficients A'_n and their standard deviations, normalized so that $A'_o = 1$, are listed in Table 3. The corresponding values from Verser's work are included for comparison.

TABLE 3

Least Square Coefficients

Verser		This Work
A'_o	1.0000 ± 0.0034	1.0000 ± 0.0026
A'_2	0.0961 ± 0.0055	0.0971 ± 0.0057
A'_4	0.0339 ± 0.0071	0.0231 ± 0.0066

MATRIX CONFIGURATIONS

$$\left\| \begin{matrix} P_o(\mathrm{Cos}90^\circ) & P_2(\mathrm{Cos}90^\circ) & P_4(\mathrm{Cos}90^\circ) \\ P_o(\mathrm{Cos}105^\circ) & P_2(\mathrm{Cos}105^\circ) & P_4(\mathrm{Cos}105^\circ) \\ P_o(\mathrm{Cos}120^\circ) & P_2(\mathrm{Cos}120^\circ) & P_4(\mathrm{Cos}120^\circ) \\ P_o(\mathrm{Cos}135^\circ) & P_2(\mathrm{Cos}135^\circ) & P_4(\mathrm{Cos}135^\circ) \\ P_o(\mathrm{Cos}150^\circ) & P_2(\mathrm{Cos}150^\circ) & P_4(\mathrm{Cos}150^\circ) \\ P_o(\mathrm{Cos}165^\circ) & P_2(\mathrm{Cos}165^\circ) & P_4(\mathrm{Cos}165^\circ) \\ P_o(\mathrm{Cos}180^\circ) & P_2(\mathrm{Cos}180^\circ) & P_4(\mathrm{Cos}180^\circ) \end{matrix} \right\|$$

(A)

$$\left\| \begin{matrix} \sigma^{-2}(90^\circ) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \sigma^{-2}(105^\circ) & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \sigma^{-2}(120^\circ) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sigma^{-2}(135^\circ) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sigma^{-2}(150^\circ) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sigma^{-2}(165^\circ) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sigma^{-2}(180^\circ) \end{matrix} \right\|$$

(B)

$$\left\| \begin{matrix} \bar{W}'(90^\circ) \\ \bar{W}'(105^\circ) \\ \bar{W}'(120^\circ) \\ \bar{W}'(135^\circ) \\ \bar{W}'(150^\circ) \\ \bar{W}'(165^\circ) \\ \bar{W}'(180^\circ) \end{matrix} \right\|$$

(C)

$$\left\| \begin{matrix} A_o \\ A_2 \\ A_4 \end{matrix} \right\|$$

(D)

FIGURE 5

A. Experimental Anisotropies

The anisotropy is defined:

$$\overline{R} = \frac{\overline{W}(180^\circ) - \overline{W}(90^\circ)}{\overline{W}(90^\circ)} \quad (22)$$

The anisotropy for the least-square curve was calculated from the experimental correlation function. Since the anisotropy can be determined with much greater precision than can the least-square coefficients themselves, it provides a more sensitive means for comparing the experimental and theoretical functions. The experimental anisotropy is

$$\overline{R} = 0.167 \pm 0.013$$

The standard deviation was calculated by the formula presented by Klema and McGowan (6). The computer program for the calculation of $\overline{R}$ and its standard deviation is outlined in Appendix I.

CHAPTER VI
RESULTS AND CONCLUSIONS

A. COMPARISON BETWEEN EXPERIMENT AND THEORY

The experimental and corrected theoretical functions for this experiment are:

Experimental:

$$\overline{W}'(\theta) = (1.0000 \pm 0.0026) + (0.0971 \pm 0.0057)\ P_2 + (0.0231 \pm 0.0066)\ P_4$$

Theoretical:

$$\overline{W}(\theta) = 1.0000 \pm 0.0996\ P_2 + 0.00838\ P_4$$

The experimental anisotropy was calculated to be $\overline{R} = 0.167 \pm 0.013$ and is compared with Verser's value of $\overline{R} = 0.171 \pm 0.027$ and with the theoretical anisotropy corrected for the solid angle, $\overline{R} = 0.161$.

Figure 6 shows the experimental results and their standard deviations for this work and that of Verser. Also shown are the least-square correlation curves for both sets of data and the corrected theoretical correlation curve. All the curves have been normalized to unity at $\theta = 90^\circ$.

B. DISCUSSION AND CONCLUSIONS

From Figure 6, it can be seen that the curve obtained in this work agrees with that obtained by Verser. Both of these curves show an apparently real dip in the region from 105° to 135°. It is only a remote possibility that this dip can be attributed to statistical fluctuations, and it is unlikely to be due to instrumental effects.

Two conjectures of possible mechanisms are:

(a) The source may have crystallized resulting in preferential alignment of the nuclei within the crystal due to internal electric fields.

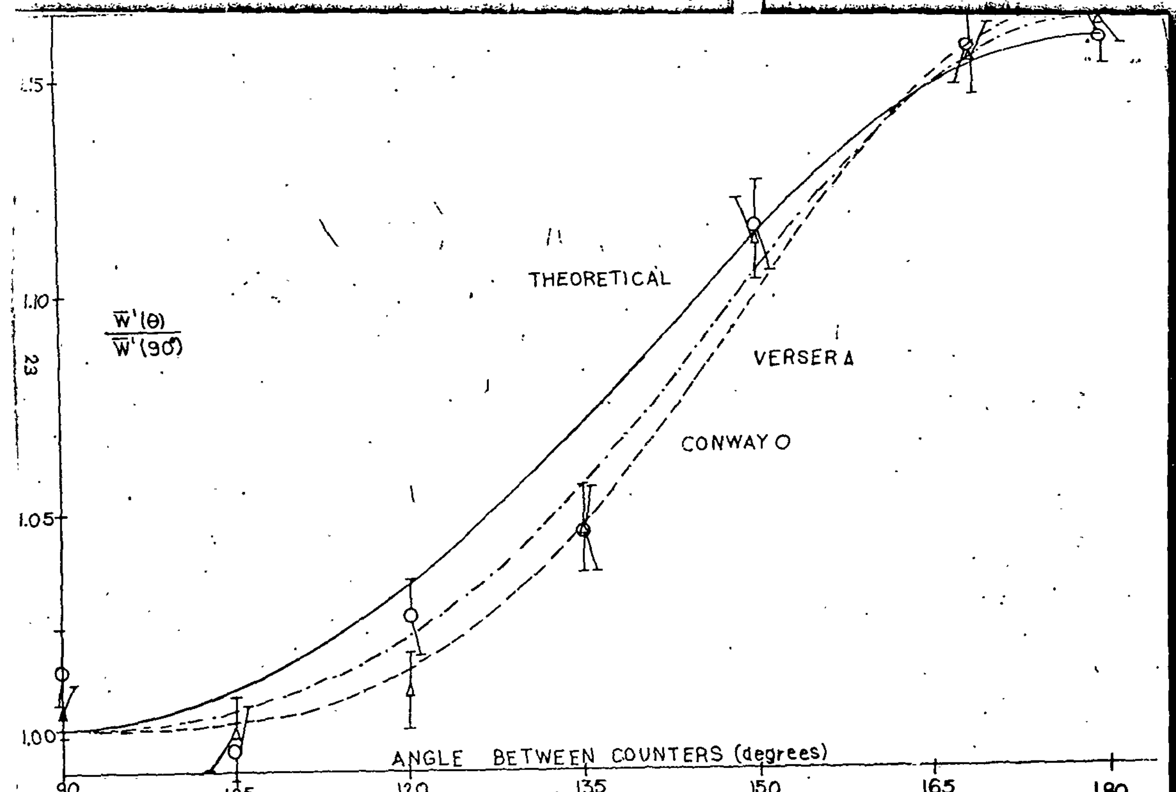

$\frac{\overline{W}'(\theta)}{\overline{W}'(90°)}$
.15
1.10
1.05
1.00
THEORETICAL
VERSER Δ
CONWAY O
ANGLE BETWEEN COUNTERS (degrees)
90
105
120
135
150
165
180

FIGURE 6

(b) The ferromagnetic properties of Cobalt could have led to a preferential alignment of the nuclei in the earth's magnetic field.

The following series of experiments are suggested for future work.

(a) The results for measurements conducted for angles between 180° and 270° should be compared with those already obtained.

(b) In order to check on the possible effects of orientation due to crystalline electric fields, the experiment should be repeated with the present source at various orientations relative to the fixed counter.

(c) In order to check on the possibility of orientation by magnetic effects the source should be placed in a magnetic field of known direction and the measurements repeated.

(d) A correlation curve using a powdered Cobalt-60 source in place of the present source should be obtained for comparison.

These experiments would determine conclusively if any effects causing preferential nuclear orientation are present.

The following instrumentation improvements are suggested in order to improve the stability of the equipment.

(a) A very stable power supply should be purchased to aid in preventing the line voltage fluctuations from interfering with the electronic system.

(b) The effect of temperature variations on the electronic system can be minimized by placing the equipment in a temperature controlled room for conducting future work.

(c) A slow coincidence unit whose resolving time is independent of the counting rate should be obtained.

The precision of the results should be improved by the addition of a fast coincidence channel working in conjunction with the slow coincidence unit to reduce the number of accidental coincidences.

Since the experimental curves using Cobalt-60 have not agreed with the theoretical curve, the experiments on Cobalt-60 should be continued until the source of the distrotion is ascertained. Perhaps the effect can be related to the physical properties of the $CoCl_2$ source.

APPENDIX I

Least-Square Fit of Experimental Results

The comparison of the experimental correlation function to the functional form of the theoretical correlation function given by Equation (1) is accomplished by the method of least-squares, as outlined by Rose (2). The analysis requires the solution of Equation (20) for the values of A'_n.

The computer solution of the matrix equation, like the solid angle calculation, is carried out in floating point format. In addition to the solution for the values of A'_n, the program also calculates the anisotropy by Equation (21), and its standard deviation by the formula presented by Klema and McGowan (6). A flow sheet outline of the program is given in Figure (7). In order to provide a certain amount of flexibility to the program, the angles used have been left as a parameter to be supplied. The program as written is, however, limited to seven different angular positions. The parameters needed for the program may be placed anywhere in the computer and their addresses supplied to the program by placing them in the B registers in the following order:

B1 = weighted means of the correlation function in ascending angular order.

B2 = the standard deveations of the weighted means in the same order as above.

B3 = the values of the angles used in ascending order.

The program is available for future use on both bioctal tape in machine language, and IBM cards in assembly language. The bioctal tape contains the following:

1. The main program for calculation of A'_n
2. The program of normalization of the A'_n
3. The program for calculation of the resulting correlation function
4. The normalization of the correlation function
5. The calculation of the anisotropy

LEAST-SQUARE FIT FLOW CHART

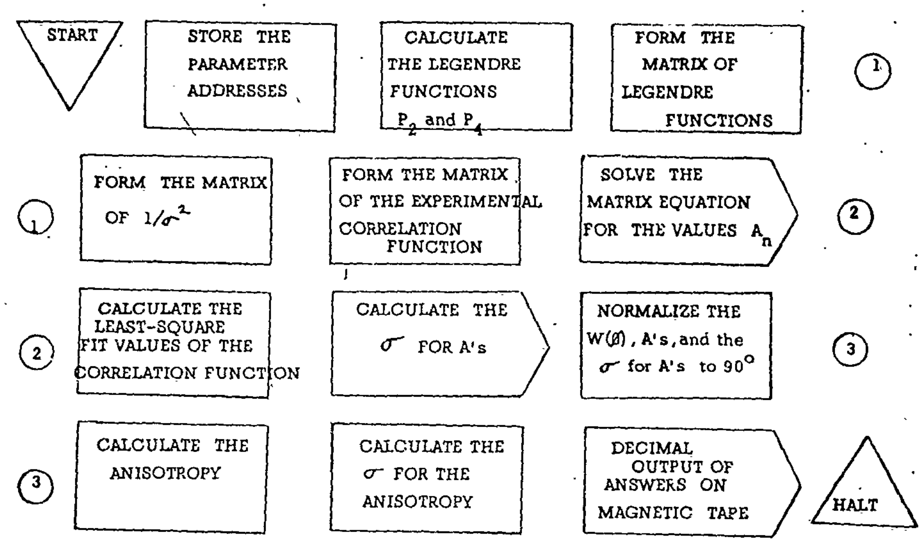


FIGURE 7

6. The calculation of the standard deviation for the anisotropy

7. The subroutines

   a. Floating Point Sine-Cosine

   b. Floating Point Square Root

   c. Floating Point Decimal Output.

The results of the computations are dumped on magnetic tape unit (4) in the following sequence:

Lines 1 thru 3	The matrix inverse
Lines 4 thru 6	Check answer; included in the program is a check of the inverse which consists of multiplying the inverse by the original matrix
Line 7	The values of A'_o, A'_2 and A'_4
Line 8	The standard deviations of the A'_n
Line 9 thru 13	The resulting correlation functions
Line 14 and 15	The normalized correlation functions
Line 16	The normalized A'_n
Line 17	The normalized standard deviations of the A'_n
Line 18	The anisotropy
Line 19	The square of the standard deviation of the anisotropy


```
        ORG   12000
        REM   BURTON J CONWAY APRIL 1961
        REM   LEAST SQUARE FIT OF ANGULAR
        REM   CORRELATION DATA.
        REM   MUST BE SUPPLIED WITH
        REM   PARAMETER ADDRESSES AS FOLLOWS.
        REM   B1  CORRELATION FUNCTION.
        REM   B2  SIGMA OF CORRELATION FUNCT. ON.
        REM   B3  ANGLES USED IN DEGREES.
ZEUS    EQU   13000
RHO     EQU   13100
TRANS   EQU   13200
ATW     EQU   13230
ATWA    EQU   13260
INVER   EQU   13500
CHECK   EQU   13520
IAT     EQU   13540
IATW    EQU   13570
ANS     EQU   13620
FINIS   EQU   13630
SINFL   EQU   60000
MATRIX  EQU   10000
```

```
                        ANISO  EQU  13624
12000   56 1 12045             SIU  1 FORMMU
        50 1 00000             ENI  1 0
12001   57 2 12032             SIL  2 SIGMA
        56 2 12033             SIU  2 SIGMA+1
12002   50 2 00000             ENI  2 0
        50 0 00000             ENI  0 0
12003   56 3 12004             SIU  3 /+1
        50 3 00000             ENI  3 0
12004   12 1 00000      START  LDA  1 0
        32 0 12512             FMU  0 CONV
12005   75 4 60001             SLJ  4 SINFL+1
        50 0 00000             ENI  0 0
12006   50 0 00000             ENI  0 0
        50 0 00000             ENI  0 0
12007   50 0 00000             ENI  0 0
        50 0 00000             ENI  0 0
12010   20 1 12463             STA  1 TEMP
        50 0 00000             ENI  0 0
12011   54 1 00006             ISK  1 6
        75 0 12004             SLJ  0 START
12012   12 1 12463      NEXT   LDA  1 TEMP     STARTS FORMATION
        32 1 12463             FMU  1 TEMP     OF THE LEG. POL.
```



```
12013   20 0 12461             STA  0 DON
        32 0 12320             FMU  0 FLT2
12014   31 0 12316             FSB  0 FLT
        33 0 12317             FDV  0 FLT1
12015   20 1 12326             STA  1 WORK2
        12 0 12461             LDA  0 DON
12016   32 0 12322             FMU  0 FLT4
        20 0 12462             STA  0 DON+1
12017   12 0 12461             LDA  0 DON
        32 0 12461             FMU  0 DON
12020   32 0 12323             FMU  0 FLT5
        31 0 12462             FSB  0 DON+1
12021   30 0 12320             FAD  0 FLT2
        33 0 12321             FDV  0 FLT3
12022   20 1 12335             STA  1 WORK4
        50 0 00000             ENI  0 0
12023   54 1 00006             ISK  1 6
        75 0 12012             SLJ  0 NEXT
12024   12 0 12325      FORM   LDA  0 WORK1
        20 2 12434             STA  2 ABLE
12025   51 2 00001             INI  2 1
        12 1 12326             LDA  1 WORK2
12026   20 2 12434             STA  2 ABLE
        51 2 00001             INI  2 1
```

```
12027  12 1 12335          LDA  1 WORK4
       20 2 12434          STA  2 ABLE
12030  51 2 00001          INI  2 1
       50 0 00000          ENI  0 0
12031  54 1 00006          ISK  1 6
       75 0 12024          SLJ  0 FORM
12032  12 0 12316  SIGMA   LDA  0 FLT
       33 1 00000          FDV  1 0
12033  33 1 00000          FDV  1 0
       20 1 12463          STA  1 TEMP
12034  54 1 00006          ISK  1 6
       75 0 12032          SLJ  0 SIGMA
12035  50 2 00000          ENI  2 0
       50 1 00000          ENI  1 0
12036  12 1 12353  FORMCAD LDA- 1 CAD
       22 0 12043          AJP  0 /+5
12037  12 2 12463          LDA  2 TEMP
       20 1 12353          STA  1 CAD
12040  51 1 00001          INI  1 1
       50 0 00000          ENI  0 0
12041  54 2 00006          ISK  2 6
       75 0 12036          SLJ  0 FORMCAD
```



```
12042  75 0 12044          SLJ  0 /+2
       50 0 00000          ENI  0 0
12043  51 1 00001          INI  1 1
       75 0 12036          SLJ  0 FORMCAD
12044  50 1 00000          ENI  1 0
       50 2 00000          ENI  2 0
12045  12 1 00000  FORMMU  LDA  1 0
       20 1 12344          STA  1 MU
12046  54 1 00006          ISK  1 6
       75 0 12045          SLJ  0 FORMMU
12047  50 1 00000          ENI  1 0
       50 2 00000          ENI  2 0
12050  75 4 10000          SLJ  4 MATRIX        TRANSPOSE
       50 0 00000          ENI  0 0
12051  50 0 00000          ENI  0 0
       50 0 00000          ENI  0 0
12052  50 0 00000          ENI  0 0
       50 0 00002          ENI  0 2
12053  50 0 00007          ENI  0 7
       50 0 12434          ENI  0 ABLE
12054  50 0 00003          ENI  0 3
       50 0 06626          ENI  0 6626
12055  50 0 00000          ENI  0 0
       50 0 13200          ENI  0 TRANS
```

```
12056   75 4 10000   SLJ  4 MATRIX   ATW
        50 0 00000   ENI  0 0
12057   50 0 00000   ENI  0 0
        50 0 00000   ENI  0 0
12060   50 0 00000   ENI  0 0
        50 0 00004   ENI  0 4
12061   50 0 00003   ENI  0 3
        50 0 13200   ENI  0 TRANS
12062   50 0 00007   ENI  0 7
        50 0 12353   ENI  0 CAD
12063   50 0 00007   ENI  0 7
        50 0 13230   ENI  0 ATW
12064   75 4 10000   SLJ  4 MATRIX   ATWA
        50 0 00000   ENI  0 0
12065   50 0 00000   ENI  0 0
        50 0 00000   ENI  0 0
12066   50 0 00000   ENI  0 0
        50 0 00004   ENI  0 4
12067   50 0 00003   ENI  0 3
        50 0 13230   ENI  0 ATW
12070   50 0 00007   ENI  0 7
        50 0 12434   ENI  0 ABLE
```



```
12071   50 0 00003   ENI  0 3
        50 0 13260   ENI  0 ATWA
12072   75 4 10000   SLJ  4 MATRIX   INVERSE
        50 0 00000   ENI  0 0
12073   50 0 00000   ENI  0 0
        50 0 00000   ENI  0 0
12074   50 0 00000   ENI  0 0
        50 0 00005   ENI  0 5
12075   50 0 00003   ENI  0 3
        50 0 13260   ENI  0 ATWA
12076   50 0 00044   ENI  0 36D
        50 0 13272   ENI  0 ATWA+12
12077   50 0 00000   ENI  0 0
        50 0 13500   ENI  0 INVER
12100   75 4 10000   SLJ  4 MATRIX   CHECK
        50 0 00000   ENI  0 0
12101   50 0 00000   ENI  0 0
        50 0 00000   ENI  0 0
12102   50 0 00000   ENI  0 0
        50 0 00004   ENI  0 4
12103   50 0 00003   ENI  0 3
        50 0 13500   ENI  0 INVER
12104   50 0 00003   ENI  0 3
        50 0 13260   ENI  0 ATWA
```

```
12105   50 0 00003   ENI 0 3
        50 0 13520   ENI 0 CHECK
12106   75 4 10000   SLJ 4 MATRIX   IAT
        50 0 00000   ENI 0 0
12107   50 0 00000   ENI 0 0
        50 0 00000   ENI 0 0
12110   50 0 00000   ENI 0 0
        50 0 00004   ENI 0 4
12111   50 0 00003   ENI 0 3
        50 0 13500   ENI 0 INVER
12112   50 0 00003   ENI 0 3
        50 0 13200   ENI 0 TRANS
12113   50 0 00007   ENI 0 7
        50 0 13540   ENI 0 IAT
12114   75 4 10000   SLJ 4 MATRIX   IATW
        50 0 00000   ENI 0 0
12115   50 0 00000   ENI 0 0
        50 0 00000   ENI 0 0
12116   50 0 00000   ENI 0 0
        50 0 00004   ENI 0 4
12117   50 0 00003   ENI 0 3
        50 0 13540   ENI 0 IAT
```



```
12120   50 0 00007   ENI 0 7
        50 0 12353   ENI 0 CAD
12121   50 0 00007   ENI 0 7
        50 0 13570   ENI 0 IATW
12122   75 4 10000   SLJ 4 MATRIX   ANS
        50 0 00000   ENI 0 0
12123   50 0 00000   ENI 0 0
        50 0 00000   ENI 0 0
12124   50 0 00000   ENI 0 0
        50 0 00004   ENI 0 4
12125   50 0 00003   ENI 0 3
        50 0 13570   ENI 0 IATW
12126   50 0 00007   ENI 0 7
        50 0 12344   ENI 0 MU
12127   50 0 00001   ENI −0 1
        50 0 13620   ENI 0 ANS
12130   50 4 00000   ENI 4 0
        50 5 00000   ENI 5 0
12131   50 6 00000   ENI 6 0
        50 1 00000   ENI 1 0
12132   50 2 00000   ENI 2 0
        50 3 00000   ENI 3 0
12133   54 1 77777   ISK 1 77777
        75 0 12133   SLJ 0 /
```

```
12134   50 0 00000     ENI  0 0
        74 7 42040     EXF  7 42040
12135   75 4 71000     SLJ  4 71000
        50 0 00000     ENI  0 0
12136   01 0 13500      01  0 INVER
        04 0 00001      04  0 1
12137   12 0 12315     LDA  0 MIKE
        70 0 12136     RAD  0 /-1
12140   54 4 00002     ISK  4 2
        75 0 12135     SLJ  0 /-3
12141   54 1 77777     ISK  1 77777
        75 0 12141     SLJ  0 /
12142   54 1 77777     ISK  1 77777
        75 0 12142     SLJ  0 /
12143   50 0 00000     ENI  0 0
        74 7 42040     EXF  7 42040
12144   75 4 71000     SLJ  4 71000
        50 0 00000     ENI  0 0
12145   01 0 13520      01  0 CHECK
        04 0 00004      04  0 4
12146   12 0 12315     LDA  0 MIKE
        70 0 12145     RAD  0 /-1
```



```
12147   54 4 00002          ISK  4 2
        75 0 12144          SLJ  0 /-3
12150   54 1 77777          ISK  1 77777
        75 0 12150          SLJ  0 /
12151   50 0 00000          ENI  0 0
        74 7 42040          EXF  7 42040
12152   75 4 71000          SLJ  4 71000
        50 0 00000          ENI  0 0
12153   01 0 13620           01  0 ANS
        04 0 00007           04  0 7
                            REM  STARTS FORMATION OF THE
                            REM  CORRELATION FUNCTION
12154   12 0 13620   DUMP   LDA  0 ANS
        32 4 12434          FMU  4 ABLE
12155   20 0 13100          STA  0 RHO     AOPO IN STORAGE
        51 4 00001          INI  4 1
12156   12 0 13621          LDA  0 ANS+1
        32 4 12434          FMU  4 ABLE    A2P2 IN A REG
12157   30 0 13100          FAD  0 RHO     AOPO+A2P2 IN THE
        20 0 13100          STA  0 RHO     A REGISTER
12160   12 0 13622          LDA  0 ANS+2
        51 4 00001          INI  4 1
12161   32 4 12434          FMU  4 ABLE    A4P4 IN A REG
        30 0 13100          FAD  0 RHO     SUM IN A REG
```

12162	20 6 13000	STA 6 ZEUS	ANS TO STORAGE
	51 6 00003	INI 6 3	
12163	54 4 00024	ISK 4 24	
	75 0 12154	SLJ 0 DUMP	
12164	12 2 13500	LDA 2 INVER	
	75 4 12527	SLJ 4 SQRFL	
12165	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12166	20 1 12501	STA 1 TTA	
	51 2 00004	INI 2 4	
12167	54 1 00002	ISK 1 2	
	75 0 12164	SLJ 0 /-3	
12170	50 1 00000	ENI 1 0	
	50 2 00000	ENI 2 0	
12171	50 3 00000	ENI $^{-}$3 0	
	50 4 00000	ENI 4 0	
12172	54 1 77777	ISK 1 77777	
	75 0 12172	SLJ 0 /	
12173	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	
12174	75 4 71000	SLJ 4 71000	
	50 0 00000	ENI 0 0	

12175	01 0 12501	01 0 TTA	
	04 0 00010	04 0 10	
12176	54 1 77777	ISK 1 77777	
	75 0 12176	SLJ 0 /	
12177	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	
12200	75 4 71000	SLJ 4 71000	
	50 0 00000	ENI 0 0	
12201	01 0 13000	01 0 ZEUS	
	04 0 00011	04 0 11	
12202	12 0 12315	LDA 0 MIKE	
	70 0 12201	RAD 0 /-1	
12203	54 5 00004	ISK 5 4	
	75 0 12200	SLJ 0 /-3	
12204	12 1 13000	LDA 1 ZEUS	NORMALIZES THE
	33 0 13000	FDV 0 ZEUS	CORRELATION
12205	20 2 12472	STA 2 NORM	FUNCTION
	51 1 00003	INI 1 3	
12206	54 2 00006	ISK 2 6	
	75 0 12204	SLJ 0 /-2	
12207	54 1 77777	ISK 1 77777	
	75 0 12207	SLJ 0 /	
12210	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	

```
12211   75 4 71000   SLJ  4 71000   DUMPS THE
        50 0 00000   ENI  0 0       NORMALIZED
12212   01 0 12472    01  0 NORM    CORRELATION
        04 0 00016    04  0 16      FUNCTION
12213   12 0 12315   LDA  0 MIKE
        70 0 12212   RAD  0 /-1
12214   54 2 00001   ISK  2 1
        75 0 12211   SLJ  0 /-3
12215   50 1 00000   ENI  1 0
        50 0 00000   ENI  0 0
12216   12 1 13620   LDA  1 ANS
        33 0 13620   FDV  0 ANS
12217   20 1 12507   STA  1 AN
        50 0 00000   ENI  0 0
12220   54 1 00002   ISK  1 2
        75 0 12216   SLJ  0 /-2
12221   54 1 77777   ISK  1 77777
        75 0 12221   SLJ  0 /
12222   50 0 00000   ENI  0 0
        74 7 42040   EXF  7 42040
12223   75 4 71000   SLJ  4 71000
        50 0 00000   ENI  0 0
```



```
12240   75 4 71000         SLJ  4 71000
        50 0 00000         ENI  0 0
12241   01 0 13624          01  0 ANISO
        04 0 00022          04  0 22
12242   12 0 12314         LDA  0 ZRO
        20 0 12514         STA  0 ROB
12243   12 1 12344   AVG   LDA  1 MU
        31 2 13000         FSB  2 ZEUS
12244   20 0 12513         STA  0 EBSIL
        32 0 12513         FMU  0 EBSIL
12245   32 3 12353         FMU  3 CAD
        30 0 12514         FAD  0 ROB
12246   20 0 12514         STA  0 ROB
        51 2 00003         INI  2 3
12247   51 3 00010         INI  3 10
        50 0 00000         ENI  0 0
12250   54 1 00006         ISK  1 6
        75 0 12243         SLJ  0 AVG
12251   12 0 12514         LDA  0 ROB
        33 0 12324         FDV  0 FLT6
12252   20 0 12514         STA  0 ROB
        50 2 00000         ENI  2 0
```

```
12224   01 0 12507     01  0 AN
        04 0 00020     04  0 20
12225   12 1 12501     LDA 1 TTA       NORMALIZES THE
        33 0 13000     FDV 0 ZEUS      SIGMAS FOR A
12226   20 1 12504     STA 1 TTAN
        50 0 00000     ENI 0 0
12227   54 1 00002     ISK 1 2
        75 0 12225     SLJ 0 /-2
12230   54 1 77777     ISK 1 77777
        75 0 12230     SLJ 0 /
12231   50 0 00000     ENI 0 0
        74 7 42040     EXF 7 42040
12232   75 4 71000     SLJ 4 71000
        50 0 00000     ENI 0 0
12233   01 0 12504     01  0 TTAN
        04 0 00021     04  0 21
12234   12 0 13022     LDA 0 ZEUS+22
        31 0 13000     FSB 0 ZEUS
12235   33 0 13000     FDV 0 ZEUS
        20 0 13624     STA 0 ANISO
12236   54 1 77777     ISK 1 77777
        75 0 12236     SLJ 0 /
12237   50 0 00000     ENI 0 0
        74 7 42040     EXF 7 42040
```



```
12253   50 3 00000     ENI 3 0
        50 1 00000     ENI 1 0
12254   12 0 12514     LDA 0 ROB
        32 1 13500     FMU 1 INVER
12255   20 2 12515     STA 2 AXE
        51 1 00004     INI 1 4
12256   54 2 00002     ISK 2 2
        75 0 12254     SLJ 0 /-2
12257   12 0 12514     LDA 0 ROB
        32 0 13501     FMU 0 INVER+1
12260   20 0 12520     STA 0 COV02
        12 0 12514     LDA 0 ROB
12261   32 0 13505     FMU 0 INVER+5
        20 0 12521     STA 0 COV24
12262   12 0 13621     LDA 0 ANS+1
        30 0 13622     FAD 0 ANS+2
12263   20 0 12522     STA 0 A24
        32 0 12522     FMU 0 A24
12264   20 0 12523     STA 0 A242
        12 0 12522     LDA 0 A24
12265   33 0 13620     FDV 0 ANS
        20 0 12524     STA 0 GET
12266   32 0 12524     FMU 0 GET
        20 0 12524     STA 0 GET
```

12267	12 0 12522		LDA 0 A24
	32 0 13620		FMU 0 ANS
12270	20 0 12522		STA 0 A24
	50 0 00000		ENI 0 0
12271	12 0 12521		LDA 0 COV24
	32 0 12317		FMU 0 FLT1
12272	30 0 12516		FAD 0 AXE+1
	30 0 12517		FAD 0 AXE+2
12273	33 0 12523		FDV 0 A242
	20 0 12525		STA 0 WIT
12274	12 0 12515		LDA 0 AXE
	33 0 13620		FDV 0 ANS
12275	33 0 13620		FDV 0 ANS
	30 0 12525		FAD 0 WIT
12276	20 0 12525		STA 0 WIT
	12 0 12520		LDA 0 COV02
12277	30 0 12521		FAD 0 COV24
	33 0 12522		FDV 0 A24
12300	32 0 12317		FMU 0 FLT1
	20 0 12526		STA 0 WIT+1
12301	12 0 12525		LDA 0 WIT
	31 0 12526		FSB 0 WIT+1

12302	32 0 12524		FMU 0 GET
	20 0 13630		STA 0 FINIS
12303	54 1 77777		ISK 1 77777
	75 0 12303		SLJ 0 /
12304	50 0 00000		ENI 0 0
	74 7 42040		EXF 7 42040
12305	75 4 71000		SLJ 4 71000
	50 0 00000		ENI 0 0
12306	01 0 13630		01 0 FINIS
	04 0 00025		04 0 25
12307	54 1 77777		ISK 1 77777
	75 0 12307		SLJ 0 /
12310	54 1 77777		ISK 1 77777
	75 0 12310		SLJ 0 /
12311	50 0 00000		ENI 0 0
	74 7 42040		EXF 7 42040
12312	74 0 42003		EXF 0 42003
	50 0 00000		ENI 0 0
12313	76 0 12000		SLS 0 12000
	50 0 00000		ENI 0 0
12314	00 0 00000	ZRO	OCT 0
	00 0 00000		
12315	00 0 00004	MIKE	0 0 4
	00 0 00001		0 0 1

```
12316   20 0 14000   FLT     DEC   1.0
        00 0 00000
12317   20 0 24000   FLT1    DEC   2.0
        00 0 00000
12320   20 0 26000   FLT2    DEC   3.0
        00 0 00000
12321   20 0 44000   FLT3    DEC   8.0
        00 0 00000
12322   20 0 57400   FLT4    DEC   30.0
        00 0 00000
12323   20 0 64300   FLT5    DEC   35.0
        00 0 00000
12324   20 0 34000   FLT6    DEC   4.0
        00 0 00000
12325   20 0 14000   WORK1   DEC   1.0
        00 0 00000
12326   00 0 00000   WORK2   BSS   7
        00 0 00000
12335   00 0 00000   WORK4   BSS   7
        00 0 00000
12344   17 5 34167   MU      DEC   .5046D-6
        17 3 10477
```



```
12345   17 5 34103           DEC   .4925D-6
        21 2 75007
12346   17 5 34222           DEC   .5109D-6
        23 0 76631
12347   17 5 34276           DEC   .5211D-6
        06 7 01135
12350   17 5 34522           DEC   .5556D-6
        22 1 24417
12351   17 5 34601           DEC   .5667D-6
        75 2 36515
12352   17 5 34751           DEC   .5907D-6
        02 3 02276
12353   20 7 07231   CAD     DEC   .6574621D+17
        17 2 43106
12354   00 0 00000           OCT   0
        00 0 00000
12355   00 0 00000           OCT   0
        00 0 00000
12356   00 0 00000           OCT   0
        00 0 00000
12357   00 0 00000           OCT   0
        00 0 00000
12360   00 0 00000           OCT   0
        00 0 00000
```

```
12361   00 0 00000      OCT   0
        00 0 00000
12362   00 0 00000      OCT   0
        00 0 00000
12363   20 7 05367      DEC   .4938271D+17
        05 2 01171
12364   00 0 00000      OCT   0
        00 0 00000
12365   00 0 00000      OCT   0
        00 0 00000
12366   00 0 00000      OCT   0
        00 0 00000
12367   00 0 00000      OCT   0
        00 0 00000
12370   00 0 00000      OCT   0
        00 0 00000
12371   00 0 00000      OCT   0
        00 0 00000
12372   00 0 00000      OCT   0
        00 0 00000
12373   20 7 05015      DEC   .4526935D+17
        20 7 37137
```



```
12374   00 0 00000      OCT   0
        00 0 00000
12375   00 0 00000      OCT   0
        00 0 00000
12376   00 0 00000      OCT   0
        00 0 00000
12377   00 0 00000      OCT   0
        00 0 00000
12400   00 0 00000      OCT   0
        00 0 00000
12401   00 0 00000      OCT   0
        00 0 00000
12402   00 0 00000      OCT   0
        00 0 00000
12403   20 7 05176      DEC   .4725897D+17
        27 1 03164
12404   00 0 00000      OCT   0
        00 0 00000
12405   00 0 00000      OCT   0
        00 0 00000
12406   00 0 00000      OCT   0
        00 0 00000
12407   00 0 00000      OCT   0
        00 0 00000
```

```
12410   00 0 00000      OCT   0
        00 0 00000
12411   00 0 00000      OCT   0
        00 0 00000
12412   00 0 00000      OCT   0
        00 0 00000
12413   20 7 04477      DEC   .4164931D+17
        37 2 35173
12414   00 0 00000      OCT   0
        00 0 00000
12415   00 0 00000      OCT   0
        00 0 00000
12416   00 0 00000      OCT   0
        00 0 00000
12417   00 0 00000      OCT   0
        00 0 00000
12420   00 0 00000      OCT   0
        00 0 00000
12421   00 0 00000      OCT   0
        00 0 00000
12422   00 0 00000      OCT   0
        00 0 00000
```



```
12423   20 7 15041            DEC   .9124087D+17
        16 1 31752
12424   00 0 00000            OCT   0
        00 0 00000
12425   00 0 00000            OCT   0
        00 0 00000
12426   00 0 00000            OCT   0
        00 0 00000
12427   00 0 00000            OCT   0
        00 0 00000
12430   00 0 00000            OCT   0
        00 0 00000
12431   00 0 00000            OCT   0
        00 0 00000
12432   00 0 00000            OCT   0
        00 0 00000
12433   20.7 05367            DEC   .4938271D+17
        05 2 01171
12434   20 0 14000    ABLE    DEC   1.0
        00 0 00000
12435   57 7 73777            DEC   -.5
        77 7 77777
12436   17 7 66000            DEC   .375
        00 0 00000
```

```
12437   20 0 14000          DEC   1.0
        00 0 00000
12440   60 0 11466          DEC   -.3995454
        73 1 10267
12441   17 7 54455          DEC   .1434268
        71 7 14727
12442   20 0 14000          DEC   1.0
        00 0 00000
12443   60 0 23777          DEC   -.125
        77 7 77777
12444   60 0 13277          DEC   -.289065
        76 5 40722
12445   20 0 14000          DEC   1.0
        00 0 00000
12446   17 7 64000          DEC   .250017
        10 7 23316
12447   60 0 11400          DEC   -.40624
        05 1 74265
12450   20 0 14000          DEC   1.0
        00 0 00000
12451   20 0 05000          DEC   .625
        00 0 00000
```



```
12452   17 7 26004          DEC   .023471
        31 0 11317
12453   20 0 14000          DEC   1.0
        00 0 00000
12454   20 0 07144          DEC   .8995
        26 4 16254
12455   20 0 05364          DEC   .684614
        13 3 47506
12456   20 0 14000          DEC   1.0
        00 0 00000
12457   20 0 14000          DEC   1.0
        00 0 00000
12460   20 0 14000          DEC   1.0
        00 0 00000
12461   00 0 00000   DCN    BSS   2
        00 0 00000
12463   00 0 00000   TEMP   BSS   7
        00 0 00000
12472   00 0 00000   NORM   BSS   7
        00 0 00000
12501   00 0 00000   TTA    BSS   3
        00 0 00000
12504   00 0 00000   TTAN   BSS   3
        00 0 00000
```

```
12507   00 0 00000   AN      BSS   3
        00 0 00000
12512   17 7 24357   CONV    DEC   .01745329252
        50 6 50451
12513   00 0 00000   EBSIL   BSS   1
        00 0 00000
12514   00 0 00000   ROB     BSS   1
        00 0 00000
12515   00 0 00000   AXE     BSS   3
        00 0 00000
12520   00 0 00000   COV02   BSS   1
        00 0 00000
12521   00 0 00000   COV24   BSS   1
        00 0 00000
12522   00 0 00000   A24     BSS   1
        00 0 00000
12523   00 0 00000   A242    BSS   1
        00 0 00000
12524   00 0 00000   GET     BSS   1
        00 0 00000
12525   00 0 00000   WIT     BSS   2
        00 0 00000
```



```
                             REM   FLOATING POINT SQUARE ROOT
12527   75 0 00000   SQRFL   SLJ   0 0              ALARM EXIT
        56 1 12552           SIU   1 SQFEXIT        STORE B1
12530   22 0 12550           AJP   0 SQFEXIT-2      TEST 0 ARGUMENT
        22 3 12527           AJP   3 SQRFL          TEST - ARGUMENT
12531   50 0 00000           ENI   0 0
        42 0 12556           SCM   0 SQMASK1        SET CORRECT
12532   05 0 00001           ALS   0 1              SIGN FOR
        03 0 00045           LRS   0 37D            EXPONENT
12533   22 3 12534           AJP   3 /+1            COMPUTE
        11 0 00002           INA   0 2              EXPONENT
12534   11 0 03777           INA   0 3777           FOR ROOT
        03 0 00001           LRS   0 1
12535   05 0 00044           ALS   0 36D            SHIFT EXPONENT
        20 0 12561           STA   0-SQERAS         AND SIGN
12536   44 0 12557           LDL   0 SQMASK2
        01 0 00004           ARS   0 4
12537   23 3 12540           QJP   3 /+1
        01 0 00001           ARS   0 1
12540   20 0 12562           STA   0 SQERAS+1
        14 0 12555           ADD   0 SQFCON3
12541   20 0 12563           STA   0 SQERAS+2
        12 0 12554           LDA   0 SQFCON2
```

```
12542   27 0 12563            DVF  0 SQERAS+2
        14 0 12553            ADD  0 SQFCON1
12543   50 1 00001            ENI  1 1
        04 0 00000            ENQ  0 0
12544   20 0 12563            STA  0 SQERAS+2
        12 0 12562            LDA  0 SQERAS+1
12545   27 0 12563            DVF  0 SQERAS+2
        14 0 12563            ADD  0 SQERAS+2
12546   01 0 00001            ARS  0 1
        55 1 12544            IJP  1 /-2
12547   01 0 00011            ARS  0 11
        42 0 12561            SCM  0 SQERAS
12550   32 0 12560            FMU  0 SQMASK3
        52 1 12527            LIU  1 SQRFL
12551   51 1 00001            INI  1 1
        57 1 12552            SIL  1 /+1
12552   50 1 00000   SQFEXIT  ENI  1 0
        75 0 00000            SLJ  0 0
12553   21 3 66405   SQFCON1  DEC  218518306D-8B45
        01 4 47436
12554   76 3 72106   SQFCON2  DEC  -302289917l4D-10B41
        43 6 47567
12555   03 0 56173   SQFCON3  DEC  154515776D-8B43
        52 7 71341
```



```
12556   20 0 00000   SQMASK1  OCT  2000000000000000
        00 0 00000
12557   37 7 77777   SQMASK2  OCT  3777777777774000
        77 7 74000
12560   20 0 14000   SQMASK3  OCT  2001400000000000
        00 0 00000
12561   00 0 00000   SQERAS   BSS  3
        00 0 00000
                              END
```

APPENDIX II

Solid Angle Correction

The solid angle correction, which must be applied to the theoretical correlation function to enable a comparison to be made with the experimental correlation function, is described by Rose (1). The correction involves the numerical evaluation of the integrals given by Equation (14):

$$I_{ni} = \int_{0}^{\gamma} P_n(\cos\phi)\,(1-e^{-T_i X_i(\phi)})\,\sin\phi\, d\phi$$

and the subsequent solutions of Equations (15) and (16).

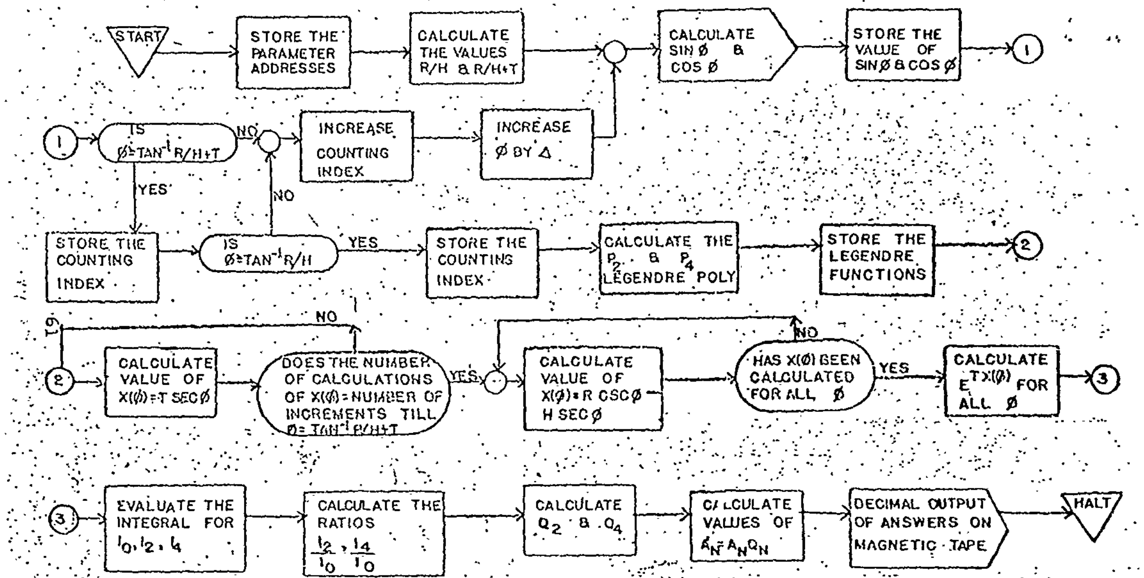
The computer solution for this correction was carried out in floating point format. The numerical integration was computed using an interval of 0.001 radians. A flow sheet outline of the program is given in Figure (8). The program must be supplied with the parameters Υ, h, r, and t same in both channels (see Table 4) thus enabling solid angle corrections to be made for any experimental set-up to which these corrections may be applicable. These parameters may be placed anywhere in the computer and their addresses supplied to the program by placing them in the B registers in the following order

B1 = r (address of the crystal radius in centimeters)
B2 = t (address of the crystal thickness in centimeters)
B3 = h (address of the crystal to source distance in centimeters)
B4 = Υ (the value of the full-energy absorption coefficient of the detector for the gamma ray in centimeters^{-1})

The values of the parameters used in the calculation of the corrected angular correlation coefficients for the theoretical correlation function and the results of the calculations are listed in Table 4.

The program is available for future use on bioctal tape in machine language and on IBM cards in assembly language. The bioctal tape contains all the necessary subroutines to enable a complete computation, i.e.

1. The main program for solution of Equation (14),
2. The subroutines



SOLID ANGLE CORRECTION FLOW CHART

FIGURE 8.

a. Floating Point Sine-Cosine

b. Floating Point Exponential

c. Floating Point Decimal Output.

The results of the computations are dumped on magnetic tape unit (4) in the following sequence:

Line 1	I_0
Line 2	I_2
Line 3	I_4
Line 4	I_2/I_0
Line 5	I_4/I_0
Line 6	Q_2
Line 7	A_2Q_2
Line 8	Q_4
Line 9	A_4Q_4

TABLE 4

SOLID ANGLE CORRECTION PARAMETERS

h (cm)	18.0
t (cm)	2.54
r (cm)	2.54
T (cm^{-1})	0.098
I_0	0.0079
I_2	0.0078
I_4	0.0076
$\frac{I_2}{I_0}$	0.9882
$\frac{I_4}{I_0}$	0.9609
Q_2	0.9765
Q_4	0.9234
Q_2A_2	0.0996
Q_4A_4	0.0084

SOLID ANGLE CORRECTION PROGRAM

```
              ORG   12000
              REM   BURTON J CONWAY APRIL 1961
              REM   SOLID ANGLE CORRECTIONS
              REM   OF THE THEORETICAL CORRELATION
              REM   CURVE.  MUST BE SUPPLIED
              REM   WITH PARAMETER ADDRESSES AS
              REM   FOLLOWS.
              REM   B1 ADDRESS OF XTAL RADIUS.
              REM   B2 ADDRESS OF XTAL THICKNESS.
              REM   B3 ADDRESS OF CRYSTAL TO
              REM   SOURCE DISTANCE.
              REM   B4 ADDRESS OF PARAMETER TAU.
        HOLD  EQU   5500
        TEMP  EQU   6500
        WORK2 EQU   7500
        WORK4 EQU   10500
        HANS  EQU   11500
        SOLD  EQU   12500
        JAYO  EQU   13500
        JAY2  EQU   13504
        JAY4  EQU   13510
        JAY20 EQU   13514
```



```
                      JAY40   EQU   13520
                      EXPFL   EQU   60600
                      SINFL   EQU   60000
12000   12 1 00000            LDA   1 0
        20 0 12163            STA   0 RAD
12001   12 2 00000            LDA   2 0
        20 0 12164            STA   0 THK
12002   12 3 00000            LDA   3 0
        20 0 12165            STA   0 HGT
12003   12 4 00000            LDA   4 0
        20 0 12166            STA   0 TAU
12004   12 0 12171            LDA   0 ZRO
        20 5 13500            STA   5 JAYO
12005   54 5 00030            ISK   5 30
        75 0 12004            SLJ   0 /-1
12006   12 0 12171            LDA   0 ZRO
        20 0 12151            STA   0 DELTA
12007   50 1 00000            ENI   1 0
        50 2 00000            ENI   2 0
12010   50 3 00000            ENI   3 0
        50 4 00000            ENI   4 0
12011   50 5 00000            ENI   5 0
        50 6 00000            ENI   6 0
```

```
12012   12 0 12163   START   LDA  0 RAD       FORMATION OF R/H
        33 0 12165           FDV  0 HGT
12013   20 0 12172           STA  0 PLEAS
        50 0 00000           ENI  0 0
12014   12 0 12165           LDA  0 HGT       FORMATION OF R/H+T
        30 0 12164           FAD  0 THK
12015   20 0 12175           STA  0 ONCE
        12 0 12163           LDA  0 RAD
12016   33 0 12175           FDV  0 ONCE
        20 0 12175           STA  0 ONCE
12017   12 0 12151   BGN     LDA  0 DELTA     SINE AND COSINE
        50 0 00000           ENI  0 0         FORMATION
12020   75 4 60001           SLJ  4 SINFL+1   COSINE
        50 0 00000           ENI  0 0
12021   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
12022   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
12023   20 1 06500           STA  1 TEMP      COSINE TO STORAGE
        12 0 12151           LDA  0 DELTA
12024   75 4 60000           SLJ  4 SINFL     SINE ROUTINE
        50 0 00000           ENI  0 0
12025   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
```



```
12026   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
12027   20 1 05500           STA  1 HOLD      SINE TO STORAGE
        33 1 06500           FDV  1 TEMP      SINE/COSINE
12030   31 0 12175   REPL    FSB  0 ONCE      SINE/COSINE-R/H+T
        22 0 12141           AJP  0 FIRST     JUMPS IF A IS 0
12031   22 2 12141           AJP  2 FIRST     JUMPS IF A IS +
        51 1 00001           INI  1 1
12032   12 0 12152           LDA  0 DELTA+1
        30 0 12151           FAD  0 DELTA
12033   20 0 12151           STA  0 DELTA
        75 0 12017           SLJ  0 BGN
12034   56 1 12105   NEXT    SIU  1 JAY+3     STARTS FORMATION OF
        56 1 12073           SIU  1 INCL+5    THE LEGENDRE POL.
12035   56 1 12111           SIU  1 JAYTO+3
        56 1 12051           SIU  1 RMK
12036   56 1 12074           SIU  1 INCL+6
        56 1 12101           SIU  1 JAY-1
12037   56 1 12115           SIU  1 JAYFR+3
        50 1 00000           ENI  1 0
12040   12 1 06500           LDA  1 TEMP      COSB IN A REG.
        32 1 06500           FMU  1 TEMP
```

```
12041   20 0 12173           STA  0 DON
        32 0 12157           FMU  0 FLT2
12042   31 0 12155           FSB  0 FLT
        33 0 12156           FDV  0 FLT1       P2 IN A REG.
12043   20 1 07500           STA  1 WORK2
        12 0 12173           LDA  0 DON
12044   32 0 12161           FMU  0 FLT4
        20 0 12174           STA  0 DON+1
12045   12 0 12173           LDA  0 DON
        32 0 12173           FMU  0 DON
12046   32 0 12162           FMU  0 FLT5
        31 0 12174           FSB  0 DON+1
12047   30 0 12157           FAD  0 FLT2       P4 IN THE A REG.
        33 0 12160           FDV  0 FLT3
12050   20 1 10500           STA  1 WORK4
        50 0 00000           ENI  0 0
12051   54 1 00000   RMK     ISK  1 0          NUMBER OF ANGLES
        75 0 12040           SLJ  0 NEXT+4     INSERTED BY PROGRAM
12052   12 0 12164   HALF    LDA  0 THK        FORMATION OF XB
        33 1 06500           FDV  1 TEMP
12053   20 1 11500           STA  1 HANS
        50 0 00000           ENI  0 0
12054   54 1 00000           ISK  1 0          NUMBER INSERTED
        75 0 12052           SLJ  0 HALF       BY PROGRAM
```



```
12055   12 1 11500           LDA  1 HANS
        32 0 12166           FMU  0 TAU
12056   20 1 11500           STA  1 HANS
        50 0 00000           ENI  0 0
12057   54 1 00000           ISK  1 0          NUMBER ENTERED
        75 0 12055           SLJ  0 /-2        BY PROGRAM
12060   12 1 11500   POWER   LDA  1 HANS       STARTS FORMATION
        75 4 60600           SLJ  4 EXPFL      OF E TO THE TAU X
12061   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
12062   20 1 12500           STA  1 SOLD
        50 0 00000           ENI  0 0
12063   54 1 00000           ISK  1 0
        75 0 12060           SLJ  0 POWER
12064   54 2 00001           ISK  2 1
        75 0 12066           SLJ  0 /+2
12065   75 0 12076           SLJ  0 HANG
        50 0 00000           ENI  0 0
12066   50 1 00000   INCL    ENI  1 0
        51 1 00001           INI  1 1
12067   12 0 12165           LDA  0 HGT        STARTS CALCULATION
        33 1 06500           FDV  1 TEMP       R CSCB-SECB
```

```
12070   20 1 12500           STA  1 SOLD
        12 0 12163           LDA  0 RAD
12071   33 1 05500           FDV  1 HOLD
        31 1 12500           FSB  1 SOLD
12072   32 0 12166           FMU  0 TAU
        20 1 11500           STA  1 HANS
12073   54 1 00000           ISK  1 0
        75 0 12057           SLJ  0 /-4
12074   50 1 00000           ENI  1 0
        56 1 12063           SIU  1 POWER+3
12075   50 1 00000           ENI  1 0
        75 0 12060           SLJ  0 POWER
12076   12 0 12155   HANG    LDA  0 FLT
        33 1 12500           FDV  1 SOLD
12077   20 1 12500           STA  1 SOLD
        12 0 12155           LDA  0 FLT
12100   31 1 12500           FSB  1 SOLD
        20 1 12500           STA  1 SOLD
12101   54 1 00000           ISK  1 0
        75 0 12076           SLJ  0 HANG
12102   12 0 12153   JAY     LDA  0 WORK       STARTS CALCULATION
        32 1 12500           FMU  1 SOLD       OF THE INTERGAL
12103   32 1 05500           FMU  1 HOLD
        32 0 12152           FMU  0 DELTA+1
```



```
12104   30 0 13500           FAD  0 JAYO
        20 0 13500           STA  0 JAYO
12105   54 1 00000           ISK  1 0
        75 0 12102           SLJ  0 /-3
12106   12 1 07500   JAYTO   LDA  1 WORK2
        32 1 12500           FMU  1 SOLD
12107   32 1 05500           FMU  1 HOLD
        32 0 12152           FMU  0 DELTA+1
12110   30 0 13504           FAD  0 JAY2
        20 0 13504           STA  0 JAY2
12111   54 1 00000           ISK  1 0          NUMBER OF TIMES
        75 0 12106           SLJ  0 /-3        TILL R/H
12112   12 1 10500   JAYFR   LDA  1 WORK4
        32 1 12500           FMU  1 SOLD
12113   32 1 05500           FMU  1 HOLD
        32 0 12152           FMU  0 DELTA+1
12114   30 0 13510           FAD  0 JAY4
        20 0 13510           STA  0 JAY4
12115   54 1 00000           ISK  1 0          NUMBER OF TIMES
        75 0 12112           SLJ  0 /-3        TILL R/H
12116   12 0 13504           LDA  0 JAY2
        33 0 13500           FDV  0 JAYO
```

```
12117   20 0 13514          STA  0 JAY20
        12 0 13510          LDA  0 JAY4
12120   33 0 13500          FDV  0 JAY0
        20 0 13520          STA  0 JAY40
12121   12 0 13514          LDA  0 JAY20
        32 0 13514          FMU  0 JAY20
12122   20 0 13524          STA  0 JAY40+4
        32 0 12167          FMU  0 THEOR
12123   20 0 13530          STA  0 JAY40+10
        12 0 13520          LDA  0 JAY40
12124   32 0 13520          FMU  0 JAY40
        20 0 13534          STA  0 JAY40+14
12125   32 0 12170          FMU  0 THEOR+1
        20 0 13540          STA  0 JAY40+20
12126   54 1 77777          ISK  1 77777
        75 0 12126          SLJ  0 /
12127   50 0 00000          ENI  0 0
        74 7 42040          EXF  7 42040
12130   75 4 71000          SLJ  4 71000
        50 0 00000          ENI  0 0
12131   01 0 13500           01  0 JAY0
        04 0 00001           04  0 1
12132   12 0 12154          LDA  0 MIKE
        70 0 12131          RAD  0 /-1
```



```
12133   54 5 00010          ISK  5 10
        75 0 12130          SLJ  0 /-3
12134   54 1 77777          ISK  1 77777
        75 0 12134          SLJ  0 /
12135   54 2 77777          ISK  2 77777
        75 0 12135          SLJ  0 /
12136   50 0 00000          ENI  0 0
        74 7 42040          EXF  7 42040
12137   74 0 42003          EXF  0 42003
        50 0 00000          ENI  0 0
12140   76 0 05000          SLS  0 5000
        50 0 00000          ENI  0 0
12141   12 0 12147  FIRST   LDA  0 SEC       MODIFIES THE PROGRAM
        20 0 12030          STA  0 REPL      WHEN THE VALUE OF
12142   12 0 12150          LDA  0 SEC+1     B  CHANGES
        20 0 12031          STA  0 REPL+1
12143   56 1 12054          SIU  1 HALF+2
        56 1 12057          SIU  1 HALF+5
12144   56 1 12063          SIU  1 POWER+3
        56 1 12075          SIU  1 INCL+7
12145   56 1 12066          SIU  1 INCL
        51 1 00001          INI  1 1
```

```
12146   75 0 12017          SLJ  0 BGN
        50 0 00000          ENI  0 0
12147   31 0 12172   SEC    FSB  0 PLEAS    PARAMETER TO MODIFY
        22 0 12034          AJP  0 NEXT     PROGRAM FOR B
12150   22 2 12034          AJP  2 NEXT     GREATER THAN R/H+T
        51 1 00001          INI  1 1
12151   00 0 00000   DELTA  OCT  0
        00 0 00000
12152   17 6 64061          DEC  .001
        11 5 64570
12153   20 0 14000   WORK   DEC  1.0
        00 0 00000
12154   00 0 00004   MIKE   0 0 4
        00 0 00001          0 0 1
12155   20 0 14000   FLT    DEC  1.0
        00 0 00000
12156   20 0 24000   FLT1   DEC  2.0
        00 0 00000
12157   20 0 26000   FLT2   DEC  3.0
        00 0 00000
12160   20 0 44000   FLT3   DEC  8.0
        00 0 00000
12161   20 0 57400   FLT4   DEC  30.0
        00 0 00000
```



```
12162   20 0 64300   FLT5   DEC  35.0
        00 0 00000
12163   20 0 25050   RAD    DEC  2.54
        75 3 41217
12164   20 0 25050   THK    DEC  2.54
        75 3 41217
12165   20 0 54400   HGT    DEC  18.0
        00 0 00000
12166   17 7 46213   TAU    DEC  .098
        20 7 12601
12167   17 7 46416   THEOR  DEC  .1020
        25 4 02030
12170   17 7 14511          DEC  .00907
        51 2 62577
12171   00 0 00000   ZRO    OCT  -0
        00 0 00000
12172   00 0 00000   PLEAS  BSS  1
        00 0 00000
12173   00 0 00000   DON    BSS  2
        00 0 00000
12175   00 0 00000   ONCE   BSS  1
        00 0 00000
                            END
```

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END